VISIBILITY PROTECTION

In the 1977 amendments to the Clean Air Act, Congress established as a national goal the prevention of any future and the remedying of any existing impairment in visibility resulting from manmade air pollution in 156 national parks and wilderness areas. The National Park Service, Forest Service, Fish and Wildlife Service, Bureau of Land Management, and Environmental Protection Agency have coordinated their efforts to make progress towards this goal. Activities include research on all aspects of the visibility issue, design and operation of a long-term visibility monitoring program, development of standard air quality/visibility simulation models for predicting new source impacts, and development and implementation of national visibility protection policies.

This document summarizes the basic understanding that the scientific and land management communities have concerning the need to protect visibility, the status and causes of visibility impairment, and trends in regional haziness. Also included are examples of the activities and results from the IMPROVE (Interagency Monitoring of PROtected Visual Environments) and the IWAQM (Interagency Work-group for Air Quality Modeling) federally coordinated programs.

What Is Visibility?

Visibility is most often thought of in terms of visual range or the furthest distance a person can see a landscape feature. However, visibility is more than *how far* one can see; it also encompasses *how well* scenic landscape features can be seen and appreciated. In the split image view from Shenandoah National Park in Figure 1, the visual range is 15 miles on the left side of the image and 65 miles on the right. The arrow shows a ridge at a distance approximately equal to the visual range. Much of the inherent scenic beauty at distances closer than 15 miles is lost in the left half of the image while scenic landscape features can be easily seen in the right half of the image. This figure illustrates that, in addition to visual range, image contrast and color are important indicators of visibility and visual air quality.

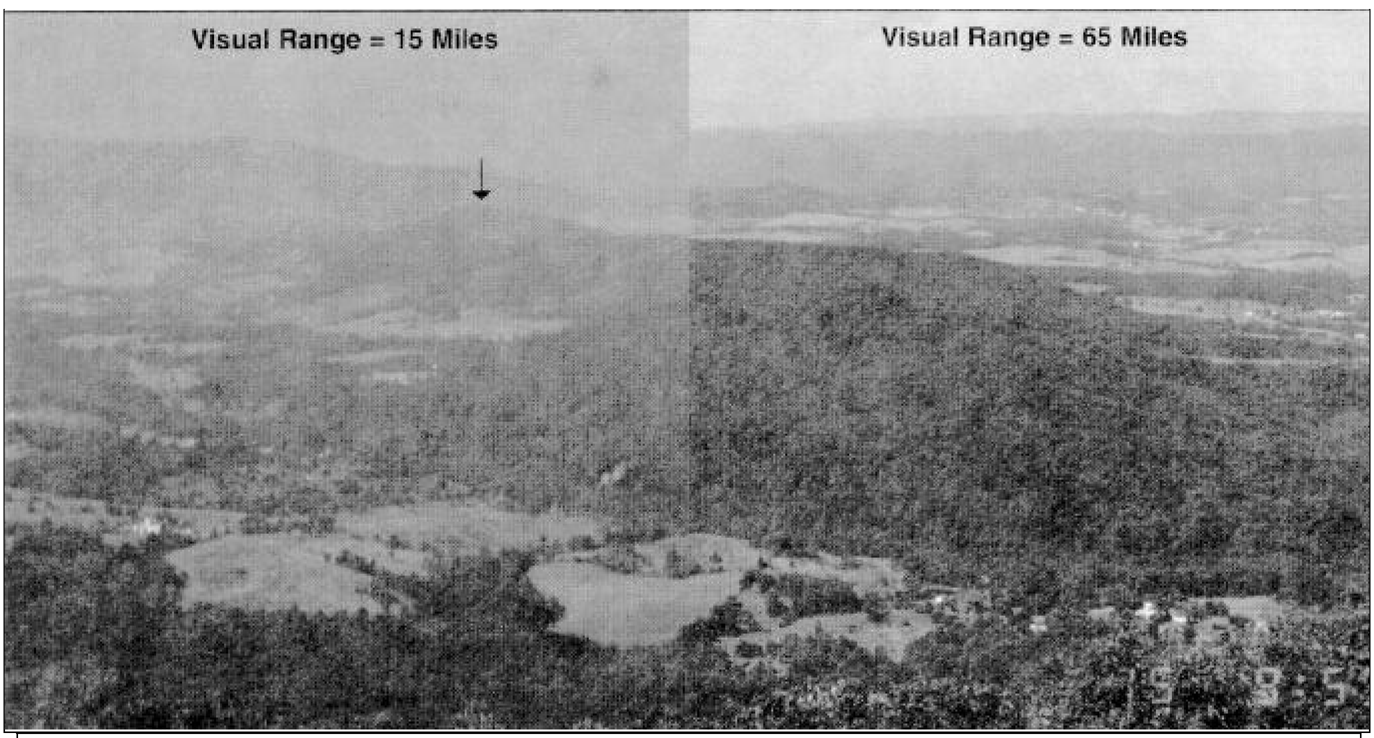

Figure 1. Split Image of a Scenic View at Shenandoah National Park with Two Levels of Visual Air Quality: Existing Summer Median (15 Miles) and Estimated Natural Background (65 Miles).

Furthermore, changes in visual range are not proportional to human perception. For example, a five mile change in visual range can result in a scene change that is either imperceptible or very obvious, depending on the baseline visibility conditions. Therefore, a more meaningful visibility index has been adopted. The scale of this visibility index, expressed in deciview (dv), is linear with respect to perceived visual changes over its entire range, analogous to the decibel scale for sound. A one deciview change represents a change in scenic quality that would be noticed by most people regardless of the initial visibility conditions. A deciview of zero equals clear air, while deciviews greater than zero depict proportionally increased visibility impairment.

What Causes Visibility Impairment?

Particles and gas molecules are responsible for visibility impairment. Visibility impairment occurs as a result of the following:

- light that forms the images we see is *scattered out* of the sight path. Light scattered out of the sight path by particles and gases never reaches the observer's eye, thereby reducing the image-forming information.
- light that forms the images we see is *absorbed in* the sight path. Some particles and gases absorb light, and absorbed light never reaches the observer.
- ambient light is *scattered into* the sight path. The addition of light scattered into the sight path competes with the image-forming light to reduce the clarity with which one can see landscape features. We have all experienced this competition between image-forming light and scattered light while driving in a snowstorm or rainstorm at night with car headlights on.

High relative humidity can also affect visibility. Although relative humidity does not by itself cause visibility to be degraded, some particles, especially sulfates, accumulate water and grow to just the right size to be very efficient at scattering light. For example, poor visibility in the eastern United States during the summer months is a result of the combination of high sulfate concentrations and high relative humidity.

The sum of scattering and absorption is referred to as atmospheric light extinction. The particles that are responsible for atmospheric light extinction are categorized as primary and secondary. Primary particles, such as smoke or road dust, are emitted directly into the atmosphere. Secondary particles are formed in the atmosphere from primary gaseous emissions. Secondary particles of concern include ammonium sulfate formed from sulfur dioxide emissions, nitrates formed from nitrogen oxide emissions, and carbon-based particles formed from hydrocarbon emissions. Some carbon is also emitted as primary particles. The only primary gaseous emission that directly reduces visibility is nitrogen dioxide because it absorbs light.

How Is Visibility Measured?

Because visibility can not be fully defined by a single parameter, monitoring only one indicator is not sufficient. The objective of visibility monitoring is to understand the effect that various types of particles and lighting conditions have on the appearance of a scene. Therefore, all visibility monitoring programs photographically docu-ment the appearance of the scene under various levels of visibility. Because it is difficult to extract quantitative information from photographs, visi-bility monitoring also includes instruments to record optical characteristics of the atmosphere and the composition of visibility reducing aerosols. Most often optical instruments meas-ure either the scattering or extinction coefficient. Aerosol monitoring determines

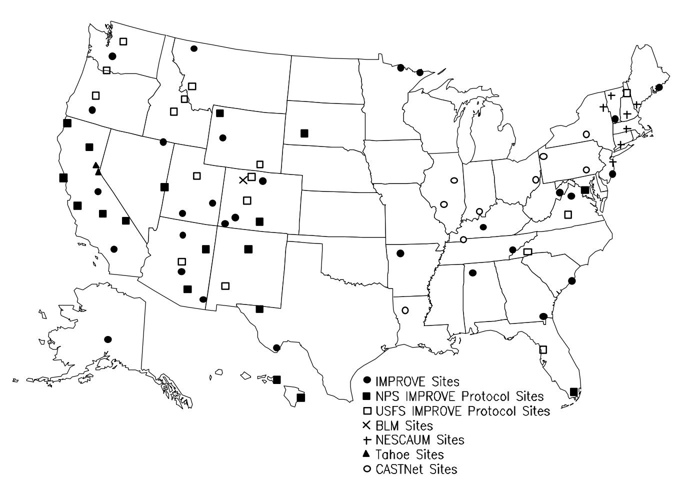

Figure 2. Visibility Monitoring Sites.

the composition of visibility reducing aerosols to help identify the source type and source strength of particles and gaseous precursors to secondary particles.

The present monitoring network protocol as recommended by IMPROVE defines that, where possible, scene, optical, and aerosol monitoring shall be conducted at each designated monitoring site. One of the principal purposes of the IMPROVE Network is to gather data that can be used to identify sources of impairment on an individual site, regional, and national scale. This network began with 20 long-term monitoring sites in 1987 and now includes over 40 sites in parks and wilderness areas across the nation. The instrumentation and monitoring protocols developed for this network have been adopted by other organizations with interests in visibility and particulate air quality resulting in more than 30 additional sites operated by individual federal, state, and local government agencies (see Figure 2) and numerous sites in 17 countries around the world.

Table 1
Estimated Natural Mean Visibility for the Eastern and Western United States along with Estimated Contributions of Particulate Categories to Reduced Visibility.

	EAST	WEST
Visual Range:	60-80 Miles (8 - 11 dv)	110-115 miles (4.5 - 5 dv)
Fine Particles	% Contribution to Visibility Reduction	
Sulfates ($(NH_4)_2 SO_4$)	9-12%	5%
Organics	19-38%	10-15%
Elemental Carbon	0.5-1%	1%
Nitrates (NH_4NO_3)	4-5%	4%
Soil Dust	2-3%	4%
Coarse Particles	6-8%	11-12%
Clean Air	33-43%	61-64%

What Are Natural Visibility Conditions?

Some light extinction occurs naturally. Scattering by the primary atmospheric gasses such as nitrogen and oxygen is called Rayleigh scattering. It is this natural scattering from atmospheric gases that causes the sky to appear blue. Naturally occurring particles also affect light extinction. Particle concentrations have only recently been routinely measured, so it is difficult to estimate natural occurring particulate levels. However, the currently accepted estimate for natural visibility in the eastern United States (East) is between 60-80 miles (8-11 dv) while in the western United States (West) it is between 110-115 miles (4.5-5 dv). Current estimates of the relative contribution of each particle type and clean air (Rayleigh scattering) to naturally occurring visibility impairment are presented in Table 1. For example, scattering by naturally occurring sulfate particles accounts for an estimated 9-12% of impairment in the East and 5% in the West. Coastlines, elevated regions (mountains), and highly vegetated areas could vary considerably from these estimates.

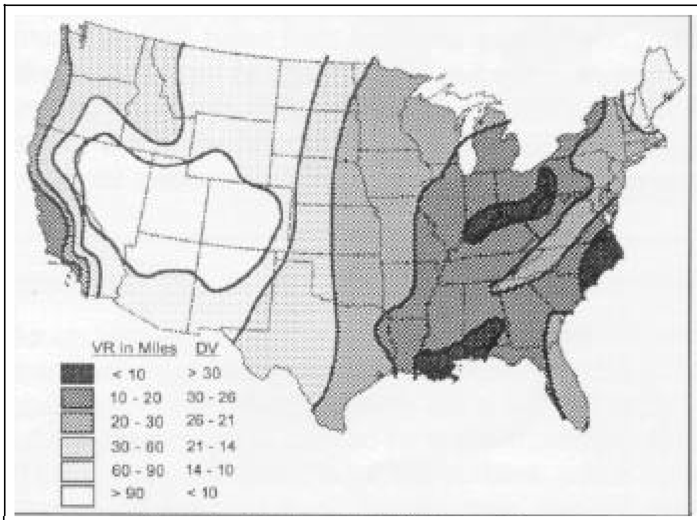

Figure 3. Median Visibility Conditions.

What Are The Current Conditions?

Visibility monitoring programs and airport observations are used to estimate the current visibility levels across the United States and to identify the relative contribution of various particle types to reduced visibility. Figure 3 is a map of mean visibility levels both in terms of visual range and deciview. While the estimated natural mean visibility (see Table 1) in the West is 110-115 miles (4.5-5 dv), the best current mean visibility, at greater than 90 miles (less than 10 dv), is found only in the inner mountain west and Great Basin regions. Moving east or west from this area, the visibility decreases quite rapidly, to approximately 10-20 miles (26-30 dv) along the west coast, and to less than 10 miles (greater than 30 dv) in much of the eastern United States where the estimated natural mean visibility is 60-80 miles (8-11 dv). Figure 3 shows a general East-West dichotomy with visual ranges being more than six times better in most parts of the West as compared to most areas east of the Mississippi.

Figures 4 and 5 show the relative contribution of sulfates and carbon-based particles, the two largest contributors to reduced visibility. In the East, 60-70% of the visibility impairment can be attributed to

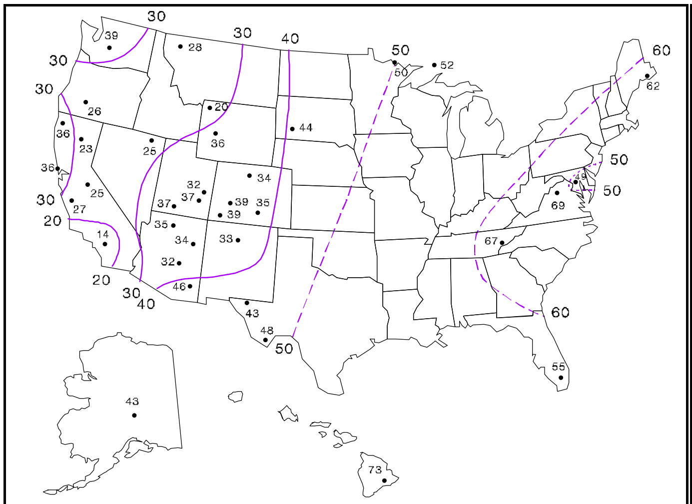

Figure 4. Percent of Visibility Impairment Caused by Sulfate Particles.

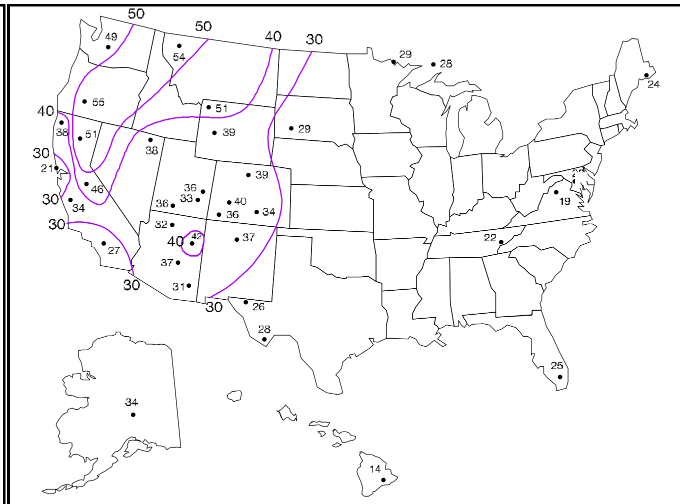

Figure 5. Percent of Visibility Impairment Caused by Carbon-based Particles.

sulfates. The sulfate contribution to reduced visual air quality decreases further west. In southern Arizona, New Mexico, and Southwest Texas, the sulfate contribution is between 40-50% while in the inner mountain west it is between 30-40%. In Nevada, Idaho, and Oregon, the sulfate contribution is less than 30%.

In the East, carbon-based particles contribute approximately 20% to human-made visibility impairment while in most parts of the West it is on the order of 30-40%. In the Northwest where there is a significant amount of prescribed fire and agricultural burning, the carbon-based particle contribution to reduced visibility is typically 50% or greater.

Wind-blown dust is usually the third largest contributor to visibility impairment; nitrates are typically less than 10%. The one exception to these general trends is the southern California monitoring site where nitrates often cause in excess of 50% of the visibility impairment.

Figures 3, 4, and 5 are representative of "rural" or remote area visibility. Visibility can be significantly different in urban areas where increased nitrates typically cause more impairment.

Are There Seasonal Trends In Visibility Impairment?

Figure 6 summarizes annual average and seasonal trends for four areas of the United States: Southwest, southern California, Northwest, and East. The height of the bar corresponds to haziness in units of extinction while the height of the shaded patterns is proportional to the contribution of various particulates to visibility degradation. In most cases, the summer months are the haziest while the

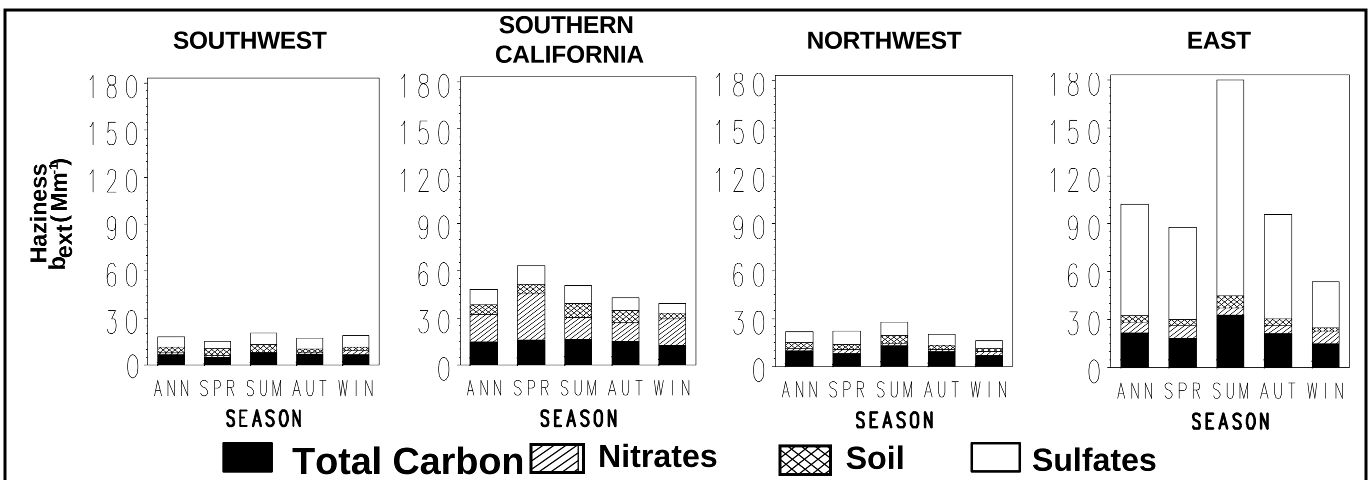

Figure 6. Summary of Seasonal Trends in Visibility Impairment for Four Geographic Regions of the United States. (The height of the bar is the total extinction value and the shaded patterns are proportional to the contribution of various particulates to visibility degradation.)

clearer months typically occur during the winter. The relative contribution of each particulate species tends not to vary from season to season.

Are There Long Term Trends In Visibility?

Figure 7 shows eastern United States median visual range and deciviews for 1948-1982. The current eastern seasonal visibility trends are quite evident. The lowest visibility occurs in the summer and the best visibility occurs in the winter. Long-term trends are also apparent. In the winter season, there was some improvement in visibility in New England and the north central U.S. from 1948-1952 to 1960-1964. However, since 1970, visibility has decreased during the winter season, especially in the Southeast. Visibility during the spring season has degraded throughout the entire eastern U.S., especially along the Gulf coast and the south and central east coast. The most dramatic changes, however, are evident during the summer months. A region of modest visibility in the eastern U.S. during 1948-1952 steadily expanded and became worse until the entire eastern U.S. and southeastern Canada are significantly degraded. Visibility during the autumn season shows significant improvement in the north central industrial areas from 1970-1974 to 1978-1982. Similar long-term trends are evident in coastal areas of California and Washington state.

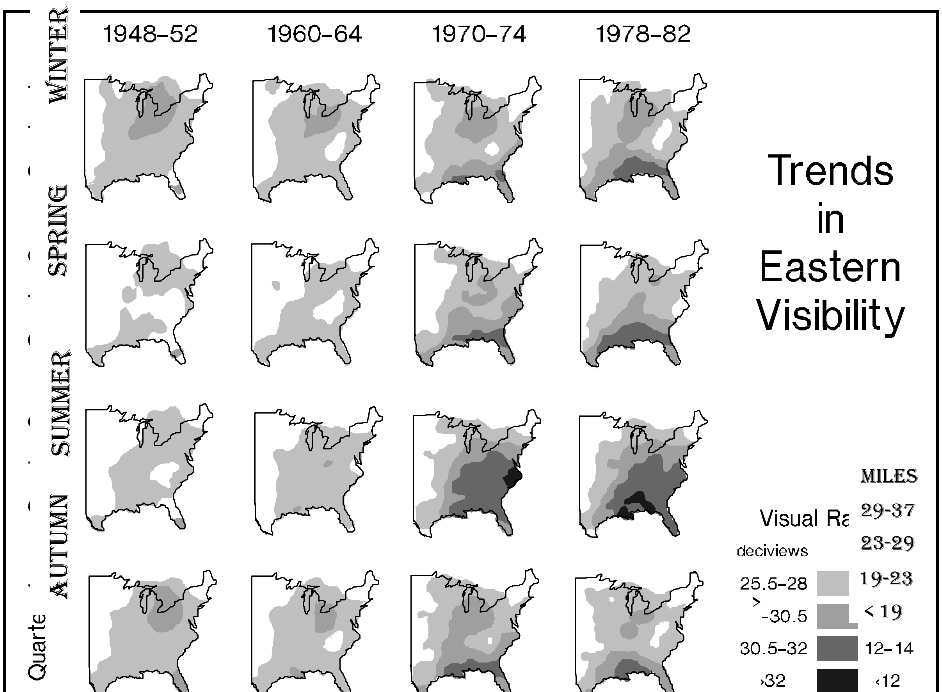

Figure 7.   Historical Record of Visibility Changes in the Eastern United S

What Are The Sources Of Visibility Reducing Particles?

Much visibility impairment is associated with sulfates which are formed from sulfur dioxide emissions. In the East most sulfur dioxide is emitted from fossil fuel-fired power plants, while in the West melting, oil extraction, and refining activity along with fossil fuel-fired power plants contribute. In some places, most of the impairment is caused by emissions from other countries. For example, at Big Bend National Park, Texas, between 60-90% of the sulfates come from sulfur dioxide emissions in Mexico, while at North Cascades National Park, Washington, most of the sulfate is attributable to sulfur dioxide emissions in Canada.

Carbonaceous material is emitted directly into the atmosphere as primary particles from forest fires, prescribed burns, agricultural burning, and from diesel emissions. Secondary organics are formed from natural gaseous hydrocarbon emissions, from automobile exhaust, and from other industrial hydrocarbon emissions. Nitrates are formed from nitrogen oxide emissions from automobiles and fossil fuel-fired power plants.

Are There Long-Term Trends Between Emissions And Visibility Reduction?

Figures 8 and 9 show sulfur emission data and visibility trend data for the southeastern and northeastern United States for the summer months. The emissions are expressed as millions of tons of sulfur/year, and visibility is expressed in deciviews. The correlation between sulfur emissions and haziness is clear. These data show that trends in sulfur emissions provide a plausible explanation for observed changes in regional visibility.

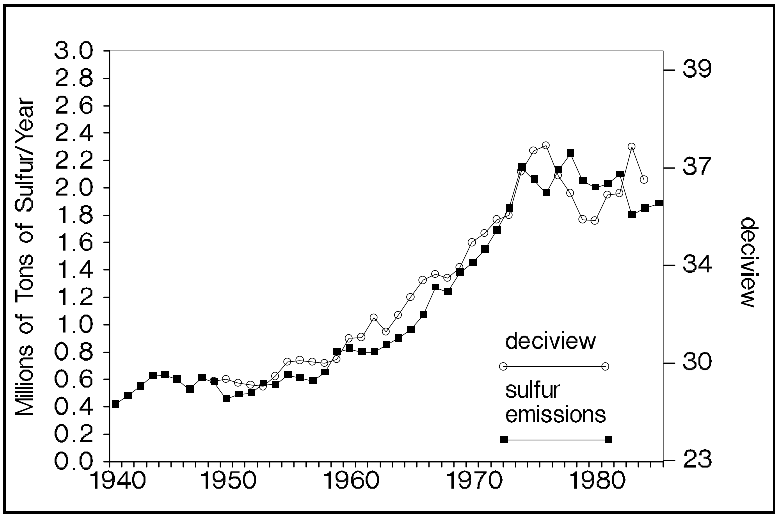

Figure 8. Relationship Between Sulfur Dioxide Emissions and Haziness in the Southeastern United States During the Summer Months.

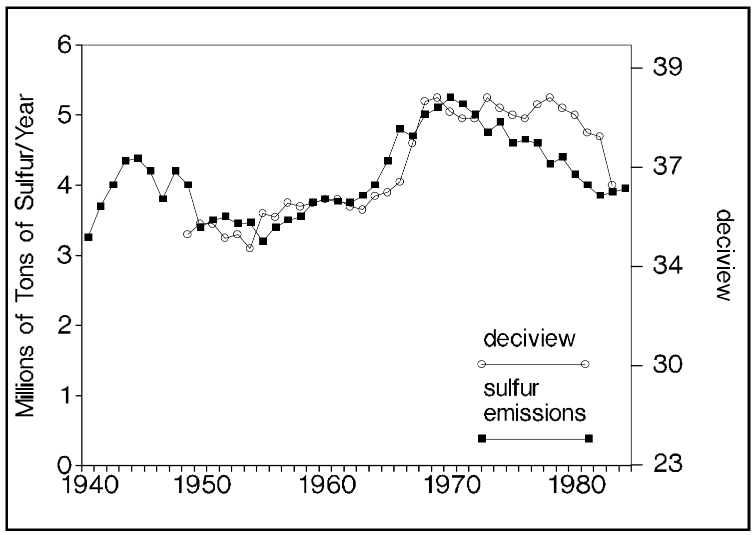

Figure 9. Relationship Between Sulfur Dioxide Emissions and Haziness in the Northeastern United States During the Summer Months.

What Steps Have The Federal Land Managers And EPA Taken To Develop Techniques To Determine The Contribution Of New And Existing Sources To Uniform Haze?

The National Park Service (NPS) has developed and applied numerous sophisticated mathematical techniques which use ambient particulate concentration and composition data in conjunction with visibility monitoring data to infer the sources of visibility impairment. The NPS has also focused a portion of its air quality research activities toward the development of a regional-scale air quality modeling capability to assist in the evaluation of source-specific impairment due to air pollution sources located or proposed to be located within several hundred kilometers of national parks and wilderness areas.

Similar model development efforts have also been undertaken by the U.S. Forest Service (USFS) and the EPA. In spite of these parallel efforts, no specific guidance for long-range transport modeling has been developed, often leading to inconsistent modeling interpretations. During discussions between the EPA, NPS, USFS, and the U.S. Fish and Wildlife Service, it was recognized that it would be in the best interests of all to cooperatively evaluate various regional scale modeling techniques suitable for the characterization of pollutant concentrations, atmospheric deposition, and uniform haze and to propose such techniques for inclusion in EPA's modeling guidelines. The four agencies entered into a formal Memorandum of Understanding in November 1991, establishing the Interagency Work-group for Air Quality Modeling (IWAQM) for the purpose of identifying or, if necessary, developing acceptable regional scale models which could be used in permitting applications.

What Is The Current Status Of IWAQM Activities?

IWAQM has issued its interim recommendations which are being used for PSD permitting activities in several states. However, due to the need to improve on the meteorological fields used in modeling analyses, the IWAQM is proceeding with the development of meteorological fields based on a dynamic model of the atmosphere which was successfully used in the National Acid and Precipitation Assessment Program (NAPAP). This work is partially completed. The improved meteorological fields have been assembled and the air quality model has been selected and subjected to preliminary testing. Full evaluation of the system against independent tracer data is underway. If the evaluation of the modeling system is successful, the IWAQM recommendations on the use of the new system should be ready by the end of the year.

What Are The Most Serious Shortcomings In Knowledge Of Visibility And Its Relationship To Emissions?

Assessing the effect of changing emissions on visibility requires an understanding of the physical-chemical processes that govern transport and dispersion, particle formation, and particle light scattering and absorption processes. Although we have learned a lot and can make significant policy decisions regarding source-specific and regional haze, some serious shortcomings in understanding the relationship between emissions and visibility impairment remain. For example:

- Because emissions are not well documented in Mexico, it is not known which of many Mexican sources contribute to visibility impairment in the United States, although it is known that they contribute significantly. Any control strategy in the United States could be offset by increases in emissions across the border. Therefore, field studies and modeling exercises to estimate Mexican emissions are essential to developing regulatory strategies within the United States.
- Much of what has been learned about visibility impairment and its relationship to source emissions has evolved from high quality routine field observations. In recent years many of the national parks have discontinued monitoring because of budgetary shortfalls. Assessing the effect of urban and industrial growth and control strategies requires continuation and, in some cases, expansion of ongoing monitoring programs.
- Better monitoring methodologies, especially in the area of optical absorption, are needed.
- A lack of understanding of what constitutes "natural conditions" limits our ability to assess progress toward the national goal of no man-made visibility impairment.
- A clearer understanding is needed on how acidic sulfate particles affect visibility. Because certain sulfate particles are acidic, it is possible that more than a one-to-one improvement in visibility can be achieved from a given reduction in sulfur dioxide.
- Modeling and monitoring the effect of carbon-based particles on visibility is not well understood, yet carbon-based particles may contribute 50% or more of the visibility impairment. How much carbon is natural versus man-made? How are carbon-based particles formed? Where do they come from? How efficient are they at reducing visibility as compared to sulfates and nitrates?
- It would be beneficial to have a better understanding of how changes in particle loadings are perceived by the human observer. How much of a change in pollution levels is required to be noticeable? How much of a change in pollution levels constitutes adverse impairment?

*The data presented in this document is a summation of the work of many scientists in the field. The current regional trends and particle contributions to visibility impairment were derived from the Interagency Monitoring Of Protected Visual Environments (**IMPROVE**) program. IMPROVE is an interagency monitoring program funded and administered by the USDI National Park Service (**NPS**), USDA Forest Service (**USFS**), USDI Bureau of Land Management (**BLM**), USDI Fish and Wildlife Service (**FWS**), and US Environmental Protection Agency (**EPA**). Other organizations in the IMPROVE program are Northeast States for Coordinated Air Use Management (**NESCAUM**), State and Territorial Air Pollution Program Association (**STAPPA**), and Western States Air Resources Council (**WESTAR**). Other information presented in this document can be found in the National Acid and Precipitation Assessment Program (NAPAP) State of Science and Technology Report Number 24 (1990).*

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